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WATER-CORE OF APPLES

BY

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(Contribution from Bureau of Plant Industry)

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WATER-CORE OF APPLES[1]

By Charles Brooks, *Senior Pathologist*, and D. F. Fisher, *Pathologist, Office of Fruit-Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

Water-core occurs in practically every important apple-growing section in the world. It has been described by writers from Europe, Africa, Australia, and America. Numerous observations have been reported as to the conditions that favor its occurrence, but apparently no extended investigation of the disease has ever been made. The opinion prevails that an excessive water supply is of first importance for the occurrence of the disease, and that excessive growth is also a contributing factor; but the studies of the present paper indicate that heavy irrigation tends to decrease water-core, that forcing with nitrate does not increase it, and that the real cause of the trouble is to be found in connection with high temperatures, intense sunlight, and the accompanying high sap concentration of the apples.

OCCURRENCE

Water-core is erratic in occurrence, causing heavy losses in some seasons and almost none in others. It occurs in all of the apple-growing sections of the United States, but is most serious in the arid and semiarid regions where orchards are under irrigation and where intense sunlight prevails.

Early Harvest, Yellow Transparent, Pound Sweet, Fall Pippin, Tompkins King, Rambo, Winter Banana, Jonathan, Delicious, Stayman Winesap, and Winesap are among the varieties most susceptible to water-core. In the eastern part of the United States losses have been most severe on the summer and fall varieties. In the Northwestern States losses have been heaviest on varieties that are held on the tree for high color; for example, Jonathan, Delicious, Stayman Winesap, and Winesap.

CHARACTERISTICS OF THE DISEASE

The characteristic of water-core that sets it off from all other diseases of the apple is the watery or glassy appearance of the flesh of the apple, due to the filling of the intercellular spaces with water or cell sap instead of with air. Sometimes practically the whole apple is involved and the watery tissue is evident through the skin; but more often the disease is confined to the tissue bordering the vascular bundles, or that adjacent to the core (pl. 1, A, C). In the first stages of the disease there may be mere dots or streaks of water-core tissue scattered through the flesh. These are always associated with the vascular bundles, and may be around the larger bundles near the core or on the smaller divisions near the surface of the apple

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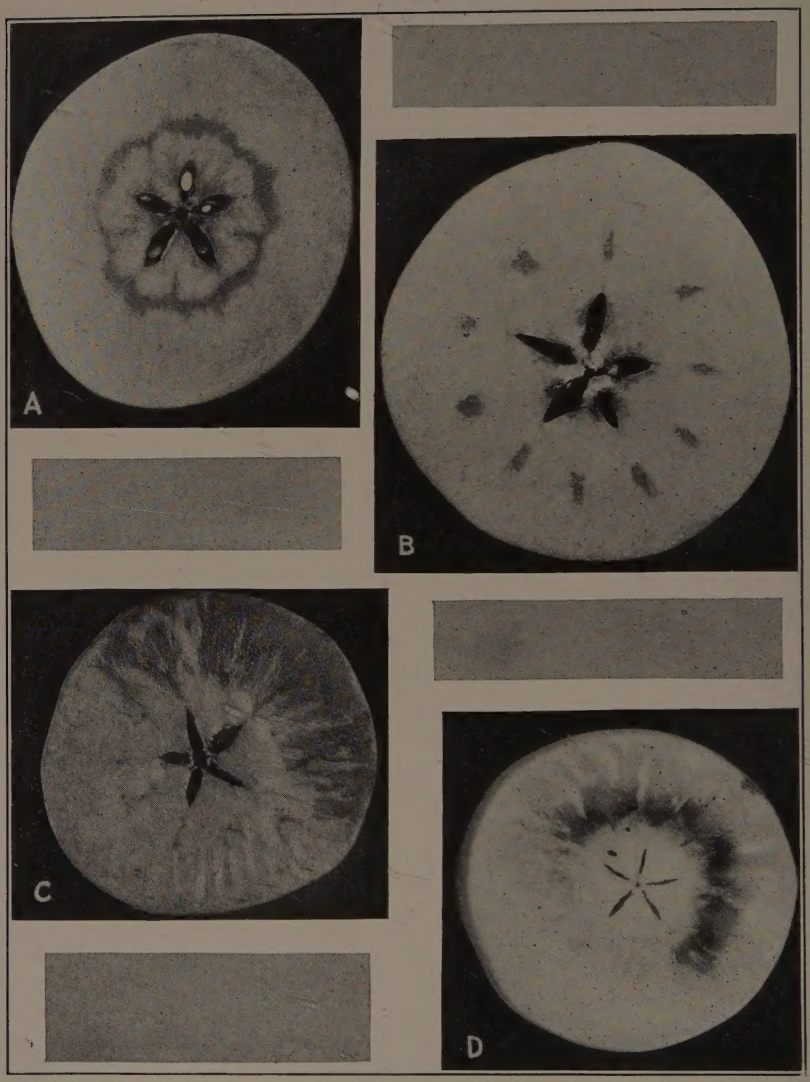

A.—Yellow Newtown apple, with bad water-core. Here the disease is confined largely to the region bordering the core

B.—Winesap apple, with water-core. Here is shown a mild form of the disease. Only the tissue immediately adjacent to the vascular bundles is affected

C.—Yellow Newtown apple, badly affected with water-core. The disease in this case is located in the sunburned half of the apple, with the core region remaining normal

D.—Yellow Newtown apple, which has partly recovered from water-core during storage. The darkest areas are still affected with the disease, while the more lightly shaded ones have an internal browning which has followed water-core

pl. 1, B). Water-core may start at a number of different points in the apple at approximately the same time, and the centers of origin may be widely separated by normal tissue. It is typically a disease of mature apples, yet it sometimes occurs several weeks before harvest.

HISTORICAL

Sorauer (*26, p. 142*)[2] apparently was the first to make a study of water-core of apples and to give a description of the disease. In his Handbuch der Pflanzenkrankheiten, published in 1886, he reported data showing that the dry weight of the water-core tissue in percentage of the fresh weight was lower than found in the normal tissue. He stated that trees were more disposed to the disease when young and first coming into bearing than they were in later years.

Cobb (*12*) apparently has given the first (1891) English description of the disease, reporting it as it was found in Australia. He reported the disease most abundant in moist seasons, and especially likely to appear after a long rain if this occurred near the time of harvest. He stated that the time at which the fruit begins to ripen is a period of rapid growth, and if the air is very moist, or if rain collects in the cavity at the stem end of the apple, the water apparently is absorbed, either through the stem or perhaps through the pip.

Arthur and Golden (*3, p. 61*) made passing reference to water-core in 1892, and Craig (*13, p. 173*) referred to it in 1896, which indicates that the disease has long been known in both the United States and Canada.

Aderhold (*2, p. 8–10*) found that water-cored tissue had a higher specific gravity and greater water content than normal tissue, but was lower in dry matter, ash, and malic acid.

Zschokke (*27, p. 195–196*) reported observations agreeing with the early studies of Sorauer and Aderhold.

Behrens (*5, p. 53*) found that partially water-cored tissue had a greater water content but less acid and invert sugar than the normal tissue.

McAlpine (*17, 18, p. 29; 19, p. 13*) reported that the disease was most common in wet years, especially if rains came about the time the apples began to ripen. He found large varieties with hard, firm flesh to be particularly susceptible to the disease, the early varieties more subject to it than the late ones, and the fruit from young trees more susceptible than the fruit from older ones.

Campbell (*9*) reported that the disease was more prevalent in moist districts and on poorly drained soils. He stated that "as the fruit matures a quantity of inefficient sap is passed in, and being unsuitable for use, and unable to escape, it water-logs the otherwise healthy cells."

Pole-Evans (*14*) stated that:

> Water-core * * * is undoubted evidence of water exudation under pressure. The cell sap fills the cells to overflowing, but instead of bursting them, quietly diffuses through their membranes or walls and then accumulates in the intercellular spaces. * * * Bitter-pit * * * results from the bursting * * * of certain cells of the flesh due to too great internal pressure. This great pressure is set up by the external conditions to which the trees are exposed.

[2] Reference is made by number (italic) to "Literature cited," p. 259.

Norton (*21*) reported the disease most abundant on summer and fall apples. He stated that:

> Apples near the top of the trees and on the sound part of branches that had been cut back by fire blight * * * were affected more than shaded apples or the slightly withered ones on the lower part of slightly blighted branches. * * * The occurrence of the disease under conditions favoring excessive sap pressure or cell turgor, on vigorous growing trees, or trees with the foliage reduced by blight, and especially in late summer when the air is cold at night and the soil warm, the cracks in the carpels, the occurrence along the vascular tissue, the liquid filling the intercellular spaces, lead me to the conclusion that the trouble is due to sap forced into the seed cavities and intercellular spaces by excessive sap pressure under conditions of reduced transpiration.

He also suggested that the rapid conversion of starch into sugar in the ripening processes of the fruit might have a bearing on the occurrence of the disease.

Bothe (*7*) noted that water-core had been particularly bad in certain years when the apples ripened much earlier than usual. He believed that excessive heat played a part in the production of the disease.

O'Gara (*22*, *23*) reported that excessive soil moisture shortly before the maturity of the fruit, if followed by extremes of temperature and atmospheric humidity, was a factor of the greatest importance in producing water-core. He found the disease worst on the south and southwest parts of the trees, and that slightly water-cored fruit largely recovered from the trouble when held in cool (not cold) storage.

Clinton (*11*, *p. 8*) thought that the unusual prevalence of water-core in Connecticut in 1913 was due to the very wet weather in October of that year, and possibly to the rapid growth of the fruit after the June–July drought.

Ramsey, McKay, Markell, and Bird (*24*) reported that water-cored King David and Tompkins King apples should not be stored, as they usually decayed early in storage. The varieties with a firm flesh, like the Winesap and Yellow Newtown, behaved much better in storage, but the water-cored apples could not be held as long as sound ones.

Hesler and Whetzel (*15*) have given a very complete summary of water-core information in their "Manual of Fruit Diseases."

Rivière and Pichard (*25*) reported comparative analyses on the two halves of a White Caville apple, one side of which was water-cored. They found that the affected part of the apple had less saccharose and less glucose than the sound part. They thought that sugars disappeared under the action of anaerobic fermentation, the acidity remaining essentially the same.

Lewis (*16*) noted that excessive thinning of Rome Beauty apples tended to aggravate water-core.

Ballard, Magness, and Hawkins (*4*, *p. 17*) found that the girdling of branches resulted in a tendency to water-core in the apples.

Birmingham (*6*) reported that water-core was probably due to heavy rains, heavy pruning, and late picking.

Adams (*1*) reported that the disease was apparently associated with several days of continuous rain just before harvest.

IRRIGATION EXPERIMENTS

A study of the literature shows a preponderance of opinion that heavy rainfall and excessive soil moisture are largely responsible for the development of the disease, and the writers deemed it desirable to test this point by irrigation experiments.

The experiments were located at Wenatchee, Wash. They were carried out in a manner similar to those reported in an earlier publication (*8*). The amount of water in the soil was determined from samples taken with a soil auger. From 200 to 300 grams of soil were in each sample. The sample was weighed, then the soil was reduced to constant weight in a drying oven at a temperature of approximately 100° C., and then was weighed again. The difference between the two weighings was taken as the moisture content of the sample, and the percentage of moisture was determined by comparing this moisture content with the dry weight of the sample.

In a part of the experiments a record was also kept of leaf moisture and evaporation conditions. The relative evaporation in the different plots was determined by means of Livingston atmometers suspended at different points in the trees. The spheres were standardized before use, and care was taken that their surfaces should not be touched, but dust and leaf hoppers made it impossible to keep them clean and necessitated frequent replacement where records were made over a long period. In the leaf-moisture studies samples consisting of 100 square centimeters were cut from the leaves of the different plots with a Ganong leaf-area cutter, care being taken to avoid the midribs and larger veins. The samples were transferred at once to small vials. They were weighed, then dried to constant weight before an electric heater at a temperature of approximately 90° C., and then weighed again to determine the loss of water.

IRRIGATION EXPERIMENTS IN 1919

The 1919 experiments were made on the Winesap and Yellow Newtown varieties. The trees were 16 years old, well grown, and very thrifty. They had received a heavy application of "complete fertilizer" in the spring, and alfalfa had been grown as a cover crop for two years prior to the starting of the experiment. The soil was a Cashmere sandy loam, somewhat stony in the Winesap orchard, but free from stones in the Yellow Newtown orchard.

The different plots were irrigated alike until the middle of July. Soil samples were taken weekly after July 7. The soil-moisture conditions for the season are shown in Figures 1 and 2. Plots 2 and 3 of the Winesap experiment received more water in August than was intended. Plot 3 should have had heavy irrigation after September 10, but the water was not available and it thus became practically a duplicate of plot 2. The Yellow Newtown irrigations were carried out practically as planned, with the exception that plot 4 did not dry out as fast as expected. It was heavily irrigated in July and August, but received no water after September 10.

A study of the figures shows that there was a distinct contrast between the soil-moisture conditions in the heavily and lightly irrigated Winesap plots, and a very decided contrast in the Yellow Newtown plots.

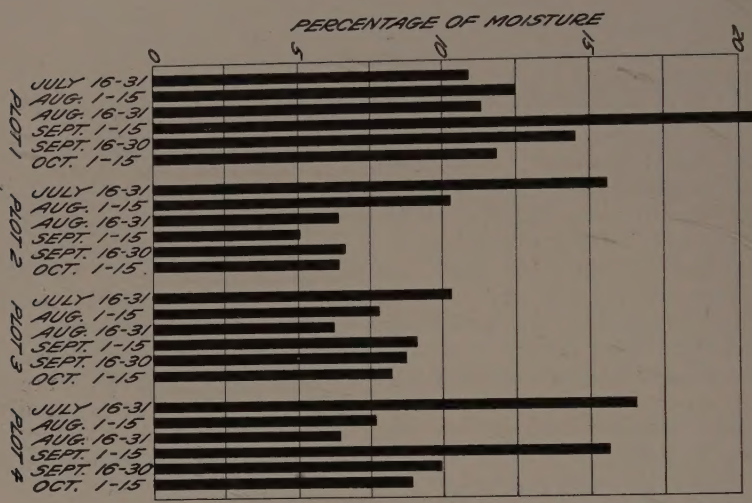

FIG. 1.—Showing the soil-moisture conditions in the irrigated plots of Winesap in 1919. The bars show the average percentage of moisture for each half month, based on the dry weight of soil samples at depths of 18 and 36 inches. Plot 1 received heavy irrigation throughout the season; plot 2, light irrigation; plot 3, light irrigation (should have been heavy after September 10); and plot 4, heavy irrigation, with 4 pounds of nitrate of soda applied per tree in the irrigation furrows on July 20

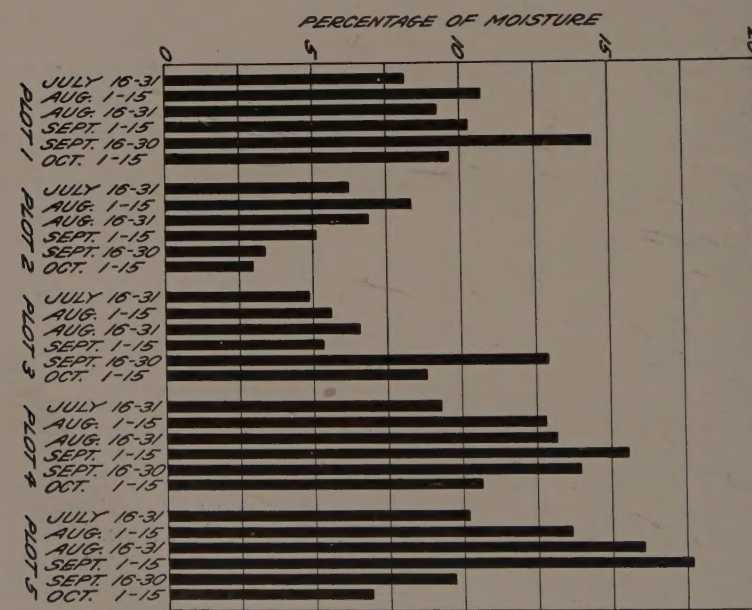

FIG. 2.—Showing soil-moisture conditions in the irrigated plots of Yellow Newtown in 1919. The bars show the average percentage of moisture for each half month, based on the dry weight of soil samples at depths of 18 and 36 inches. Plot 1 received heavy irrigation throughout the season; plot 2, light irrigation; plot 3 light irrigation until Sept. 10, then heavy irrigation; plot 4, heavy irrigation throughout the season, with the addition of 8 pounds of nitrate of soda per tree; and plot 5 heavy irrigation until September 10, then no irrigation

TABLE I.—*Evaporation in the Yellow Newtown irrigation plots, 1919*

Period of record and location of the atmometer	Evaporation ratio, cubic centimeters evaporated per atmometer	
	Heavy irrigation	Light irrigation
Period of Aug. 23 to 30, 1919:		
Atmometer in top of tree	172.5	188.0
Atmometer on lower south side of tree	148.5	170.5
Atmometer on lower north side of tree	148.5	157.0
Average for the above three atmometers during the following periods:		
7 p. m. Aug. 23 to 7 a. m. Aug. 24	7.6	7.5
7 a. m. to 7 p. m. Aug. 25	11.0	13.8
7 p. m. Aug. 25 to 7 a. m. Aug. 26	16.5	17.3
7 a. m. to 7 p. m. Aug. 26	16.7	19.3
7 p. m. Aug. 26 to 7 a. m. Aug. 27	13.3	14.8
7 a. m. to 7 p. m. Aug. 27	17.0	21.7

TABLE II.—*Percentage of moisture in Yellow Newtown leaves, irrigation experiments of 1919 (each record is based on approximately 100 square centimeters of leaf area)*

Time of collecting	Location of leaves	Percentage of moisture based on dry weight of leaf tissue	
		Heavy irrigation	Light irrigation
3.30 p. m. Aug. 27	Top of tree	146.0	121.0
Do	Lower south side	141.5	127.1
Do	Lower north side	145.5	----------
7.30 p. m. Aug. 27	Top of tree	173.5	141.9
Do	Lower south side	118.0	126.8
Do	Lower north side	151.3	143.8
9 a. m. Aug. 28	Top of tree	173.5	134.2
Do	Lower south side	135.3	132.6
Do	Lower north side	157.8	127.8

The evaporation and leaf-moisture conditions in the heavily irrigated and the lightly irrigated Yellow Newtown plots are shown in Tables I and II. The irrigation effects were evident in the foliage and the surrounding air as well as in the soil-moisture conditions. The leaves from the heavily irrigated plot were surrounded by a more humid atmosphere and had a higher percentage of moisture than those of the lightly irrigated plot. There was no contrast, however, in the general appearance of the foliage or the fruit of the different plots.

On July 20, 4 pounds of nitrate of soda were applied to each tree in plot 4. The fertilizer was applied in the furrows and worked in with the irrigation water.

The Winesap apples were picked October 24, and the Yellow Newtown October 28. Heavy freezes occurred on the nights of October 25 and 26 and the Yellow Newtown were frozen to the core. Picking was delayed until the apples had thawed, and no damage was evident. Plots 1 and 4 of the Winesap experiment had heavier crops than Plots 2 and 3, but in the Yellow Newtown experiment the fruit was evenly distributed over the different plots.

TABLE III.—*Effect of irrigation and fertilizers upon the size of apples (Winesap and Yellow Newtown experiments, 1919)*

Variety, plot, and treatment	Percentage of apples of the following size			
	2¾ inches or less	2¾ to 3 inches	3 to 3¼ inches	3¼ to 3½ inches
Winesap:				
Plot 1, heavy irrigation	59.5	30.4	9.1	1.0
Plot 2, light irrigation	26.2	50.5	20.4	2.9
Plot 3, light irrigation	24.9	45.0	25.3	4.8
Plot 4, heavy irrigation, with sodium nitrate	66.5	25.5	6.1	1.9
Yellow Newtown:				
Plot 1, heavy irrigation	24.3	30.7	26.6	18.4
Plot 2, light irrigation	48.8	29.4	17.8	10.0
Plot 3, light irrigation followed by heavy	33.1	34.1	20.3	12.5
Plot 4, heavy irrigation, with sodium nitrate	33.1	37.6	21.1	8.2
Plot 5, heavy irrigation, followed by light	29.1	30.3	27.9	12.7

The apples from the different plots were graded according to size, with the results shown in Table III. Plots 1 and 4 of the Winesap had a relatively large percentage of the smallest size (2¾-inch or smaller), probably due to the result of heavy crop on these plots; while plots 1 and 5 of the Yellow Newtown had a relatively small percentage of this size.

There was no water-core visible on the Winesap at picking time, and only a little on the Yellow Newtown. From 2 to 6 boxes of apples were saved from each plot and placed in cellar storage. Approximately half of these were cut on November 12 and the percentage of water-core determined. The results are shown in Table IV.

TABLE IV.—*Effect of irrigation upon water-core (Winesap and Yellow Newtown apples; notes taken November 12, 1919)*

Variety, plot, and treatment	Percentage of water-core				
	2¾ inches or less	2¾ to 3 inches	3 to 3¼ inches	3¼ to 3½ inches	Total all sizes
Winesap:					
1. Heavy irrigation	36.1	85.6	61.4	60.0	46.3
2. Light irrigation	40.7	71.1	81.0	100.0	73.8
3. Light irrigation	66.7	81.5	77.5	91.0	77.4
4. Heavy irrigation, with sodium nitrate	50.1	67.6	71.9	40.0	55.7
Yellow Newtown:					
1. Heavy irrigation	7.8	17.8	29.0	46.9	23.7
2. Light irrigation	10.4	26.2	46.0	62.8	26.7
3. Light irrigation till Sept. 10, then heavy	7.4	13.9	30.8	54.5	20.3
4. Heavy irrigation, with sodium nitrate	7.3	25.3	29.2	36.4	21.1
5. Heavy irrigation till Sept. 10, then none	7.5	26.1	36.2	50.0	26.5

There was more water-core in the lightly irrigated apples than in the heavily irrigated ones, and there was more where heavy irrigation was followed by light than where light was followed by heavy. The fertilizer results are discussed on page 239.

IRRIGATION EXPERIMENTS IN 1920

The irrigation experiments on Winesap were continued in 1920, but in a different orchard from that used in 1919. The trees were 8 years old, well pruned, and well cared for generally. They had made an average terminal growth of 2 feet the previous season. The soil was Cashmere sandy loam and was very uniform and very retentive of moisture. The orchard was in alfalfa and had been continuously for three years previous.

The irrigations were carried out more satisfactorily than in the previous year. The soil-moisture conditions are shown in Figure 3. It will be seen that there was a very marked contrast between the two plots, the one receiving heavy irrigation having from 7 to 10 per cent of moisture continuously after the middle of July, while the one that received light irrigation had 6.5 per cent in July, 5 per cent in August, and 3 to 4 per cent in September and October.

TABLE V.—*Evaporation in the Winesap irrigation plots, July 19 to September 18, 1920*

Period of record	Evaporation ratio, cubic centimeters evaporated per atmometer			
	In top of tree		In crotch of tree	
	Heavy irrigation	Light irrigation	Heavy irrigation	Light irrigation
July 19 to July 27	42.94	42.32	39.55	39.62
July 27 to Aug. 4	32.54	36.03	31.55	34.21
Aug. 4 to Aug. 12	24.12	27.60	23.28	26.32
Aug. 12 to Aug. 19	26.52	29.46	24.60	28.70
Aug. 19 to Aug. 26	17.29	19.92	16.12	18.73
Aug. 26 to Sept. 2	12.36	13.20	11.20	13.99
Sept. 2 to Sept. 11	17.78	20.16	18.10	19.55
Sept. 11 to Sept. 18	11.04	12.18	10.04	11.91

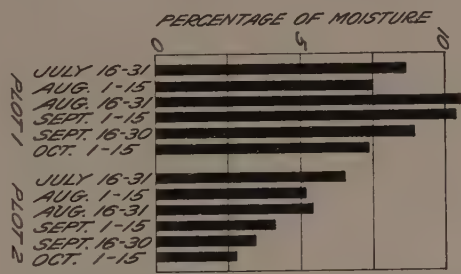

FIG. 3.—Showing the soil-moisture conditions in the irrigated plots of Winesap in 1920. The bars show the average percentage of moisture for each half month, based on the dry weight of soil samples at depths of 18 and 36 inches. Plot 1 received heavy irrigation, and plot 2 light irrigation, throughout the season

A record was kept of leaf moisture and evaporation under the different irrigation conditions. The evaporation data are reported in Table V. As in the 1919 experiment, the rate of evaporation was decidedly higher in the lightly irrigated plot than in the heavily irrigated one. It was also higher in the top of the tree than in the region of the lower limbs. Seven leaf-moisture tests were made in August, three in September, and two in October, but, contrary to results of the preceding year, the data showed practically no contrast between the foliage of the heavily irrigated trees and that of the lightly irrigated ones.

The weather was cool and cloudy during the last week of August and the first week of September and was accompanied by a strong development of color on the fruit. The apples of plot 2 took on a higher color than those of plot 1. The apples in both plots increased in diameter rapidly throughout the latter part of the season up to October 8 and at a slower rate after that until October 25, when the fruit was picked. (See fig. 8.) No contrast was evident in the foliage of the different plots, and there was but little difference in the percentages of apples of the different sizes. (See Table VI.)

TABLE VI.—*Effect of irrigation upon the size of the apples (Winesap experiments, 1920)*

Plot and treatment	Percentage of apples of the following sizes			
	2¾ inches or less	2¾ to 3 inches	3 to 3¼ inches	3¼ to 3½ inches
1. Heavy irrigation	33.4	40.5	20.6	5.5
2. Light irrigation	37.2	42.7	19.4	0.7
3. Regular orchard irrigation	43.9	35.7	16.8	3.6

The picked fruit was stored in air-cooled and cellar storage till November 26 and 27, when the apples were cut open and notes taken on water-core. The results are shown in Table VII.

TABLE VII.—*Effect of irrigation upon water-core (Winesap apples; notes taken November 26 and 27, 1920)*

Plot and treatment	Percentage of water-core				
	2¾ inches or less	2¾ to 3 inches	3 to 3¼ inches	3¼ to 3½ inches	Total all sizes
1. Heavy irrigation	31.6	48.0	67.6	70.3	47.8
2. Light irrigation	81.7	97.7	100	100	92.2
3. Regular orchard irrigation	51.7	93.7	100	100	79.2

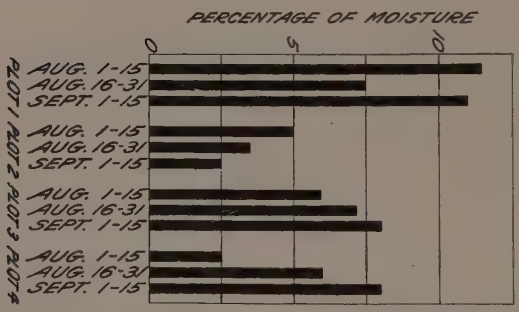

FIG. 4.—Showing the soil-moisture conditions in the irrigated plots of Winesap in 1921. The bars show the percentage of moisture, based on the dry weight of the soil. The results are the average of samples taken from depths of 18 and 36 inches. Plot 1 received heavy irrigation throughout the season, and plot 2 received no irrigation after June 27

The apples from the lightly irrigated trees had nearly twice as much water-core as those from the heavily irrigated ones. The apples from plot 3 receiving the regular orchard irrigation, which was medium as compared with the other plots, also had a very much higher percentage of water-core than the apples from the heavily irrigated trees.

IRRIGATION EXPERIMENTS IN 1921

The experiments were continued in the orchard used in 1920, but on trees that had not been included in the previous plots. Owing to a shortage of help, the irrigation work was not carried out as carefully nor were the soil samples taken as frequently as in previous years. The approximate soil-moisture conditions for August and the first half of September are shown in Figure 4. The dry plot received no water after June 27, while the others received frequent irrigations throughout the remainder of the season. On August 31,

there was a decided contrast between the wet and dry plots, as evidenced by the smaller size of the leaves and sparser foliage on the lightly irrigated trees. Plot 1 was given a heavy irrigation at this time and another irrigation on September 16. It is believed that the soil-moisture contrasts shown in Figure 4 were maintained till the apples were picked.

Red spiders and leaf hoppers were bad throughout the orchard, causing considerable foliage injury.

On July 14, 7½ pounds of nitrate of soda were applied to each tree in plot 3, and 7½ pounds muriate of potash to each tree in plot 4. The fertilizers were applied in the furrows and worked in with the irrigation water.

The fruit was picked on October 13, and held in the shade in the open till October 29, when the apples were cut open and notes taken on water-core. The results are shown in Table VIII.

TABLE VIII.—*Effect of irrigation upon the development of water-core (Winesap apples in 1921; notes taken October 29)*

Plot and treatment	Percentage of water-core		
	Bad	Slight	Total
1. Heavy irrigation	3	38	41
2. Light irrigation	8	29	37
3. Medium irrigation, with nitrate of soda	1	6	7
4. Medium irrigation, with muriate of potash	1	15	16

The lightly irrigated apples had more bad water-core but less slight water-core than the heavily irrigated ones. The total percentage of the disease was slightly greater on the heavily irrigated apples. Plots 3 and 4 with medium irrigation and applications of fertilizers had the least water-core. (For discussion of fertilizers see p. 239.)

IRRIGATION EXPERIMENTS IN 1922

The work was continued in the Winesap orchard used in 1920 and 1921. The irrigations were carried out as planned and the contrasts in soil moisture were very satisfactory. Soil samples were taken every week at 18-inch and 36-inch depths. The results are shown in Figure 5.

On June 17, 5 pounds of nitrate of soda were applied to each tree in plots 5 and 6 and 5 pounds of muriate of potash to each tree in plots 7 and 8. The trees of plot 5 were included in the nitrate plot, and those of plot 7 in the potash plot of the 1921 experiment.

The growth conditions were good in all of the plots throughout the year and no contrast was evident in foliage or fruit. The apples were picked October 24, with a yield of approximately 8 bushels per tree. The apples remained in the shade in the orchard till November 4, when they were graded for size, and from two to three boxes of apples from each plot cut open and examined for water-core. The remainder of the apples was placed in cellar storage and a second record made on November 23. The percentage of apples of the different sizes from the various plots is shown in Table IX and the water-core results in Table X.

TABLE IX.—*The effect of irrigation and fertilizers upon the size of the apples (Winesap experiment, 1922)*

Treatment	Percentage of apples of the following sizes:			
	2¾ inches or less	2¾ to 3 inches	3 to 3¼ inches	3¼ to 3½ inches
1. Heavy irrigation	49.3	40.6	8.8	1.3
2. Light irrigation	47.0	43.0	9.1	.9
3. Light irrigation followed by heavy	38.8	44.3	15.3	1.6
4. Heavy irrigation followed by light	63.1	30.0	6.9	.0
5. Nitrate of soda in 1921 and 1922	11.4	55.3	30.8	3.5
6. Nitrate of soda in 1922 only	26.1	56.4	16.1	1.4
7. Muriate of potash in 1921 and 1922	30.5	41.0	22.3	6.2
8. Muriate of potash in 1922 only	42.1	50.5	6.4	1.0

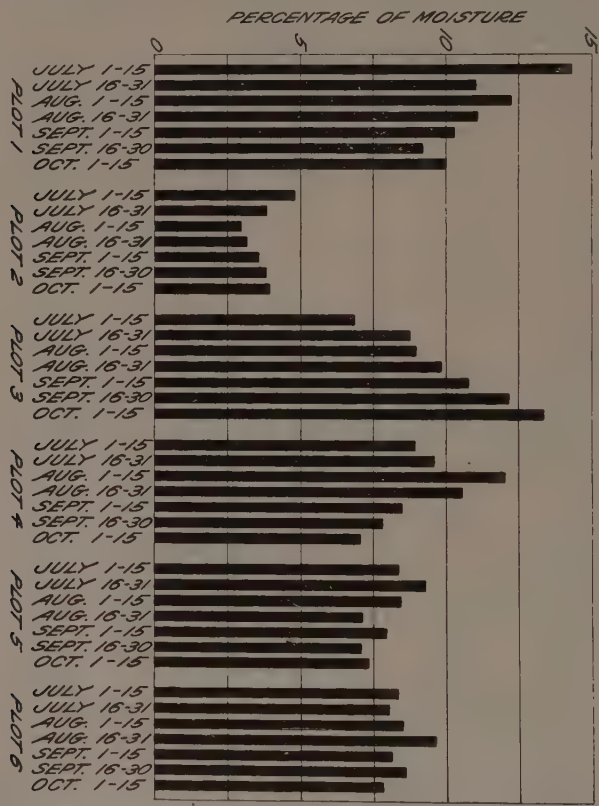

FIG. 5.—Showing the soil-moisture conditions in the Winesap irrigation plots of 1922. The bars show the average percentage of moisture, based on the dry weight of soil samples taken from depths of 18 and 36 inches. Plot 1 received heavy irrigation throughout the year; plot 2, light irrigation; plot 3, light irrigation until Aug. 20, then heavy; plot 4, heavy irrigation until Aug. 20, then light; and plots 5 and 6, medium to heavy irrigation, and an application of nitrate of soda

The percentages of apples of the different sizes were approximately the same on the heavily and lightly irrigated plots. With those receiving heavy irrigation followed by light there was a relatively large number in the smaller or 2¾-inch size; and with those receiving light irrigation followed by heavy, and also with the fruit from the nitrate plots there was a relatively large number in the larger sizes.

TABLE X.—*The effect of irrigation and fertilizer upon the development of water-core (Winesap apples in 1922)*

Plot, treatment, and date of note taking. (For degree of irrigation see fig. 5)	Percentage of water-core in the following sizes:				
	2¾ inches or less	2¾ to 3 inches	3 to 3½ inches	3¼ to 3½ inches	Total, all sizes
Notes of Nov. 4:					
Plot 1, heavy irrigation (heavy irrigation the previous year)	74.0	82.5	87.9	87.7	81.9
Plot 2, light irrigation (light irrigation the previousyear)	74.9	82.4	100.0	----------	78.6
Plot 3, light irrigation till Aug. 20, then heavy (not treated in previous experiments)	38.3	57.1	86.7	100.0	49.2
Plot 4, heavy irrigation till Aug. 20, then light (not treated in previous experiments)	67.2	82.4	84.6	----------	76.5
Plot 5, nitrate of soda in 1921 and 1922	87.5	94.8	98.4	100.0	95.6
Plot 6, nitrate of soda in 1922 only	95.2	98.6	100.0	100.0	98.0
Plot 7, muriate of potash in 1921 and 1922	86.2	92.7	98.2	100.0	93.0
Plot 8, muriate of potash in 1922 only	94.0	92.4	94.1	94.3	93.2
Notes of Nov. 23:					
Plot 1	43.2	53.9	90.5	100.0	53.1
Plot 2	85.7	81.9	88.4	80.0	84.4

The apples that received light irrigation followed by heavy had less water-core than those that received heavy irrigation followed by light. If the records of both November 4 and 23 are considered, the apples from trees receiving continuous heavy irrigation after July 1 had decidedly less water-core than those from trees receiving light irrigation during the same period. (For discussion of size of fruit and effect of fertilizers, see pp. 239 and 241.)

IRRIGATION EXPERIMENTS IN 1923

The experiments were carried out in a 12-year old Winesap orchard. The trees were uniform and in excellent vegetative condition. An alfalfa cover crop had been maintained for the two years previous. The orchard had a gentle slope both lengthwise of the rows and diagonally across them. The soil was of the Quincy fine sandy loam type, underlaid at a depth of about 30 inches by a rather heavy clay loam that became still heavier at a depth of 36 inches. At 48 inches gravel was found in all the plots, with the exception of plot 2, and in this a sticky gray clay was found at the 4-foot depth.

Irrigation was begun by the grower on May 7. Each irrigation was continued 3 days before the water was changed, and the interval between irrigations was 13 days. The special irrigations for the water-core experiments were begun the last of July, and the soil-moisture conditions for the remainder of the season are shown in Figure 6. It was found soon after the experiment was started that the dry plots were being subirrigated from the more heavily irrigated ones higher on the slope. The upper row of the dry plot was disregarded thereafter in the experiment and was considered as a buffer row, and all of the soil and fruit samples were taken from the lower row. Even with this precaution there was little contrast between the soil-moisture conditions in the wet and dry plots at the 36-inch depth. Heavy rains the last of September and the first of October also interfered with the irrigation plans. Plot 3 was intended to be dry after August but it did not dry out much. In spite of these various difficulties, it will be seen from Figure 8 that a fair contrast was maintained between the soil-moisture conditions

in the wet and those in the dry plot at the 18-inch depth, and the sap-concentration studies reported later (Table XX) furnish evidence that the irrigation effects actually reached the foliage and fruit.

The soil temperature in the different plots and under different orchard conditions was taken at intervals throughout the season, readings being taken from a depth of about 4 inches. The results are shown in Table XI. The soil in the dry plot was sometimes a few degrees warmer than that in the wet plot. The clean-cultivated soil was warmer than that in alfalfa.

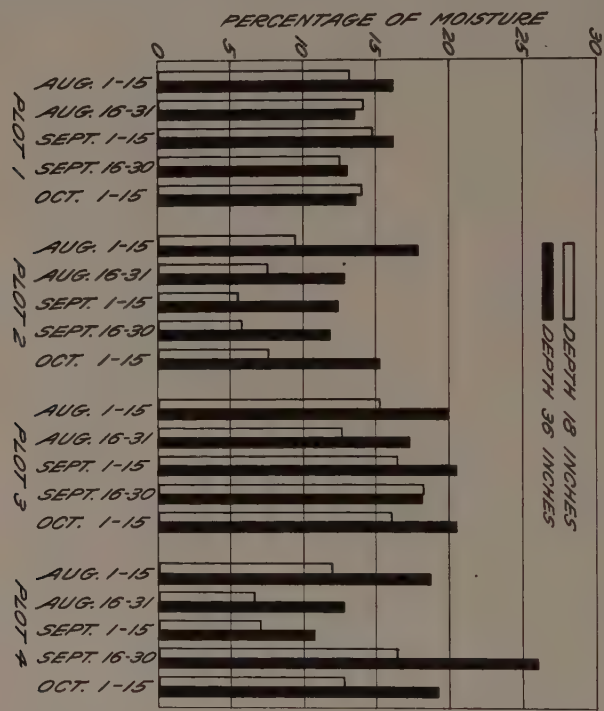

FIG. 6.—Showing the soil-moisture conditions in the irrigated plots of Winesap in 1923. The bars show the percentage of moisture, based on the dry weight of samples taken from depths of 18 and 36 inches. Plot 1 received heavy irrigation after July; plot 2, light irrigation; plot 3 was intended to have heavy irrigation followed by light; and plot 4 received light irrigation from July 27 to September 14, then heavy irrigation

TABLE XI.—*Soil and air temperature in the Winesap plots, 1923*

Date	Hour	Air temperature	Soil temperature						
			Plot 1	Plot 2	Plot 3	Plot 4	Clean cultivation	8-year alfalfa	2-year alfalfa
July 27	10 a. m.	86		71			74	68	
Aug. 4	do	72	63	66					
Do	10.30 a. m.	85					74	68	68
Aug. 27	10.00 a. m.	79	69	69	68	72	78	68	70
Sept. 10	3 p. m.	88	67	70	75				
Sept. 17	2.30 p. m.	85	63	67	68	73	65	62	
Oct. 1	10.00 a. m.	59	57						
Oct. 7	do	70	60						
Oct. 21	do	58	47						

During August considerable leaf injury became evident. This probably was a result of spraying. The edges of the leaves were scorched, and some defoliation occurred.

On October 16 it was noticed that the apples were beginning to drop badly throughout the orchard and were apparently ripe, but the experimental plots were not picked until October 21. The fruit was held in air-cooled storage until October 31, when half of the apples from each lot were cut open and examined for water-core. The results are shown in Table XII.

TABLE XII.—*The effect of irrigation upon the development of water-core (Winesap experiment, 1923)*

Plot and treatment	Percentage of water-core		
	Slight	Bad	Total
1. Heavy irrigation after July	56.1	1.4	57.5
2. Light irrigation after July	64.6	2.5	67.1
3. Heavy irrigation in July and August; no water after Aug. 31	53.7	28.8	82.5
4. Light irrigation to Sept. 14, followed by heavy irrigation	79.4	8.8	88.2

The lightly irrigated apples had more water-core than the heavily irrigated ones, and those that were heavily irrigated during July and August, with no irrigation in September or October, had the most bad water-core of all, but not as high total percentage of water-core as the apples from plot 4 which received light irrigation followed by heavy.

IRRIGATION EXPERIMENTS IN 1924

The experiments were carried out in an 18-year-old King David orchard. The trees had been well cared for and were in a good growing condition. The soil was Quincy fine sand with a loamy texture. Soil samples were taken every week at 18-inch and 36-inch depths. The soil-moisture conditions of the season are shown in Figure 7.

The soil-moisture in plot 2 was much lower during the latter part of the season than that of plots 1 and 3, and the foliage of the plot showed some tendency to wilt on extremely hot days, but there was no indication that the trees of this plot were really suffering from drought. Leaf-moisture tests based on the dry weight of whole leaf material collected September 3 gave 93.8 per cent of moisture in the leaves from the heavily irrigated plot and 86.4 per cent in the leaves from the lightly irrigated plot.

On June 3, 5 pounds of nitrate of soda were applied to each tree in plot 3.

The main commercial picking of the orchard was made September 5 and 6. At this time a bushel sample of apples was taken from the exposed top on the south side and another from the shaded interior of each count tree. The apples were held in basement storage at a temperature of about 70° until September 16, when they were graded according to size and cut open for notes on water-core. There was no water-core on the apples from the shaded interior of the trees. The results on the exposed apples are shown in Tables XIII and XIV.

TABLE XIII.—*Effect of irrigation and fertilizer upon the size of King David apples, 1924*

Treatment	Percentage of apples of the following sizes			
	2¾ inches or less	2¾ to 3 inches	3 to 3¼ inches	3¼ to 3½ inches
Picked Sept. 5 and 6:				
Plot 1, heavy irrigation	80	19	1	0
Plot 2, light irrigation	76	17	6	1
Plot 3, heavy irrigation, with sodium nitrate	79	19	2	0
Picked Sept. 25:				
Plot 1, heavy irrigation	67	30	3	0
Plot 2, light irrigation	61	38	1	0
Plot 3, heavy irrigation, with sodium nitrate	54	41	5	0

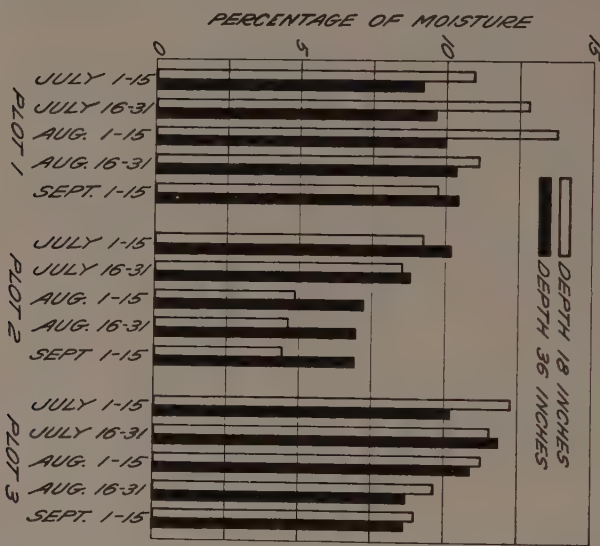

FIG. 7.—Showing the soil-moisture conditions in the King David irrigation plots of 1924. The bars show the percentage of moisture for each half month, based on soil samples taken at depths of 18 and 36 inches. Plot 1 received heavy irrigation throughout the season; plot 2, light irrigation; and plot 3, heavy irrigation, with five pounds of sodium nitrate per tree (spaded into the irrigation furrows) on June 3

TABLE XIV.—*Effect of irrigation upon water-core (King David apples, 1924)*

Plot and treatment	Percentage of water-core in apples of the following sizes			
	2¾ inches or less	2¾ to 3 inches	3 to 3¼ inches	Total, all sizes
Picked Sept. 5 and 6:				
Plot 1, heavy irrigation	0.9	0	0	0.7
Plot 2, light irrigation	.5	0	0	.4
Plot 3, heavy irrigation, with sodium nitrate	1.0	0	0	.8
Picked Sept. 25:				
Plot 1, heavy irrigation	56.8	89.5	100.0	82.7
Plot 2, light irrigation	80.0	100.0	100.0	87.8
Plot 3, heavy irrigation, with sodium nitrate	46.8	75.0	100.0	61.0

At the time of the regular picking, an upper branch with southern exposure was left unpicked on one tree of each plot, to determine the later development of water-core. The apples from these branches were picked September 25. At that time they had a deep-red color and were beginning to soften. Notes on the size of the apples and on the percentage of water-core were taken September 27. The results are shown in Tables XIII and XIV.

With the picking of September 5 and 6 the small apples had a higher percentage of water-core than the large ones, and the heavily irrigated apples a higher percentage than the lightly irrigated ones, but as no lot had more than 1 per cent of the apples affected it would seem that little weight should be given to the results.

By the time of the September 25 picking, more than three-fourths of the apples had developed water-core. The lightly irrigated apples had a higher percentage affected than the heavily irrigated ones, and the large apples a decidedly higher percentage of the disease than the small ones.

SUMMARY OF IRRIGATION EXPERIMENTS

The irrigation experiments cover a period of six years with 5 separate tests on Winesap, 1 on Yellow Newtown, and 1 on King David. In all of the experiments except one, where the percentage of the disease was large enough to be significant, the lightly irrigated fruit had more water-core than the heavily irrigated and in most cases the contrast was decided. The exception was in the case of the Winesap experiment of 1921, where 37 per cent of the lightly irrigated apples and 41 per cent of the heavily irrigated ones were affected with water-core. It has already been pointed out that the irrigation plans were not carried out as satisfactorily in this experiment as they were in the others, and it is probable that this fact accounts for the failure to obtain similar results.

In the 1919 experiments on Yellow Newtown and the 1922 experiments on Winesap, the apples that received heavy irrigation followed by light had more water-core than those that received light irrigation followed by heavy. In the 1923 experiments on Winesap, the apples receiving heavy irrigation followed by light had more bad water-core but less total water-core than those that received light irrigation followed by heavy.

The results as a whole give no indication that a sudden excess of soil moisture is a factor in the production of water-core, but, on the contrary, show that a liberal supply of water tends to make the fruit less susceptible to the disease, and this apparently holds for the latter part of the season as well as earlier in the year.

FERTILIZER EXPERIMENTS

Fertilizer experiments carried out on Yellow Newtown in 1919, on Winesap in 1919, 1921, and 1922, and on King David in 1924 have been reported in connection with the irrigation data in Tables IV, VII, X, and XIV. Similar tests were made on Jonathan in 1921, 1922, 1923, and 1924. In all of these experiments the fertilizer was worked into the soil in the bottom of the irrigation furrow, giving opportunity for it to pass rapidly into the soil solution. High-grade commercial nitrate of soda and muriate of potash were used in all cases.

The Jonathan tests were made on trees that were 14 years old at the beginning of the experiment. The soil was Wenatchee fine sandy loam. In 1921 the fertilizer was applied on July 16, in 1922 on June 6, in 1923 on July 9, and in 1924 on June 9. In 1921, 7½ pounds of nitrate of soda was applied to each tree in the nitrate plot, and 7½ pounds of muriate of potash to each tree in the potash plot. In 1922 the applications were reduced to 5 pounds per tree. In 1923 the nitrate application consisted of 5 pounds per tree, and the potash 3½ pounds per tree; and in 1924 the nitrate application was 5 pounds per tree, and the potash 6 pounds per tree.

The trees that were continued in the nitrate plot a second year had a somewhat darker green and heavier foliage than the other trees and produced apples with less color, but the potash fertilizers had no effect upon the general appearance of the foliage and fruit even after applications in four consecutive years. The terminal growth was greater on the fertilized trees than on the unfertilized ones. Measurements taken October 9, 1924, showed that the terminal growth in untreated trees averaged 13.2 centimeters; that in trees which had received nitrate one year, three years, and four years averaged 13.1, 20.2, and 24.2 centimeters, respectively; and that in trees which had received potash one year, three years, and four years averaged 17.2, 13.8, and 19.4 centimeters, respectively. It was found at picking time that the trees of the nitrate and potash plots had a slightly higher percentage of apples of the larger sizes than the untreated trees.

TABLE XV.—*Effect of nitrate of soda and muriate of potash upon the development of water-core in Jonathan apples*

Year and treatment	Percentage of water-core		
	Nitrate	Potash	No fertilizer
1921, apples picked Oct. 15; [a] notes taken Oct. 22	53.7	43.5	84.7
1922, apples picked Sept. 22; notes taken Oct. 25:			
Fertilizer in 1922 only	22.9	38.3	47.4
Fertilizer in 1921 and 1922	18.8	36.1	
1923, apples picked Sept. 14	8.6	6.2	20.3
1923, apples picked Oct. 5 [a]	34.6	71.8	47.2
1924, apples picked Sept. 6; notes taken Sept. 17:			
Fertilizer in 1924 only	4.6	4.0	16.3
Fertilizer in 1921, 1922, 1923, and 1924	2.8	0.8	

[a] Apples picked in October were past their best commercial stage.

The effects of the various fertilizer treatments upon water-core are shown in Table XV. It will be seen that in every instance the apples from the nitrate plots had less water-core than those from the unfertilized plots, and in every instance except one the apples from the potash plots also had less of the disease than the apples from the untreated plots.

The results of the fertilizer tests on Yellow Newtown and King David apples reported in Tables IV and XIV are in agreement with those on Jonathan. Water-core was decreased on both varieties by the use of nitrate and decreased on King David by the use of potash. There was no potash experiment on Yellow Newtown.

The results on Winesap apples (reported in Tables IV, VIII, and X) were not so consistent. In 1921 water-core was decidedly less on this variety when nitrate was used, but in 1919 and 1922 there was slightly more of it. In 1921 the disease was less in amount when potash was used, but in 1922 there was more of it.

The results of the experiments as a whole indicate that applications of nitrate or potash fertilizer tend to prevent the development of water-core. The results are not sufficiently striking to recommend fertilizers as a remedy for the disease, but they certainly make it conclusive that the forcing of the fruit with potash or nitrate is not to be feared as an agency in the production of water-core. The reason for the favorable effects of fertilizers is considered later in connection with the studies on shade and maturity (pp. 21 and 24).

SIZE AND GROWTH RATE OF APPLES AS RELATED TO IRRIGATION, FERTILIZERS, AND WATER-CORE

In connection with the irrigation and fertilizer experiments, a study was made of the effect of the various treatments upon the size and the growth rate of the apples and also of the relation of size to the occurrence of water-core.

The effect of the various orchard treatments upon the size of the apples at picking time is shown on page 240, and in Tables III, VI, IX, and XIII. It would be expected that the plots receiving heavy irrigation and heavy applications of nitrate would show a relatively high percentage of large apples, but the data show that in general they had but little if any greater relative yield of the larger sizes than the unfertilized and lightly irrigated plots. The total yields from the heavily irrigated and nitrated plots averaged slightly higher than the yields from the others, and it is possible that this may account for their failure to distinctly surpass the others in percentage of large-sized apples.

Fortunately the question of growth stimulus was not left entirely to records on the picked fruit. Actual growth records were kept on apples from the different plots by repeated caliper measurements and by means of auxographs (MacDougal type) (*20*).

In the caliper work representative apples were tagged and their diameters measured at a particular hour of the day. A few days later another set of measurements was taken of the same apples at approximately the same hour. At the first reading the contact surfaces of the calipers were coated with blue wax, and this left a permanent mark on the apples that made it possible to take later measurements at the same point and along the same diameter. The jaws of the calipers had a spring release, thus applying the same pressure on the apples in the different readings.

The growth records for the apples in the irrigation plots of 1920 are shown in Figure 8. Equally striking contrasts were obtained in 1922, 1923, and 1924. In all cases the apples of the heavily irrigated plots enlarged very much more rapidly than those of the lightly irrigated ones.

The only complete growth record on the fertilizer plots was made in 1921, on the Jonathan variety. The record was based on caliper measurements of 25 representative apples from each plot. The apples of the nitrate plot increased from an average diameter of 1.865 inches on July 16 to an average diameter of 3.081 inches on

October 15; the apples of the potash plot from an average diameter of 1.873 inches to an average diameter of 2.967 inches in the same period, and the apples from the unfertilized plot from an average diameter of 1.823 inches to an average diameter of 2.919 inches. The average increase in diameter in the nitrate plot was 1.216 inches, in the potash plot 1.094 inches, and in the unfertilized plot 1.096 inches. This falls far short of the contrast obtained in the irrigation plots, but indicates that the growth rate of the apples in the nitrate plot was somewhat more rapid than that of the apples in the unfertilized plot.

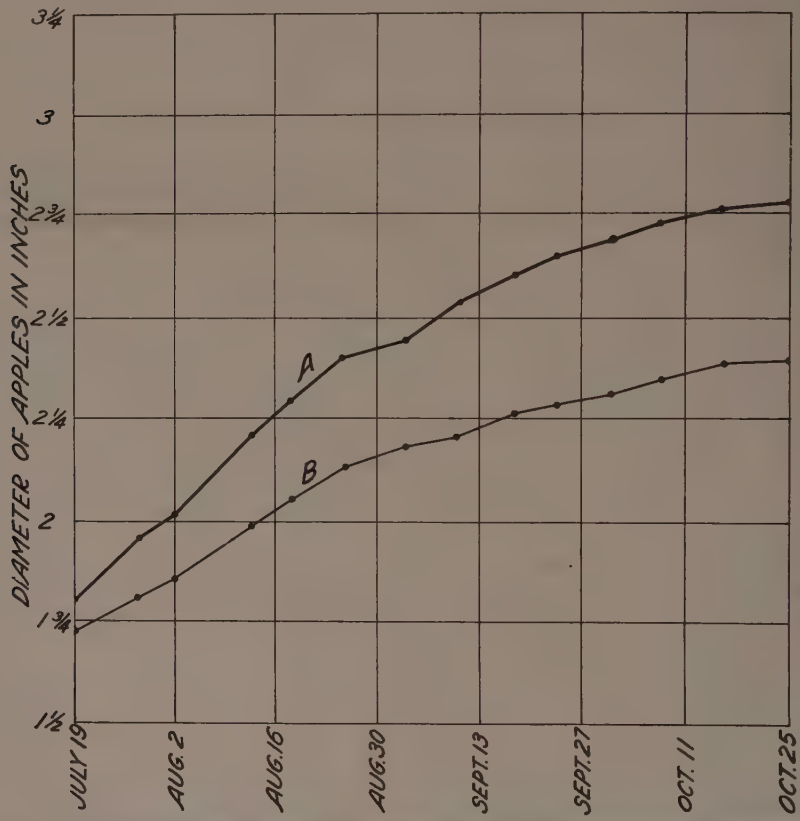

FIG. 8.—Growth rate of Winesap apples in the irrigation plots of 1920, based on caliper measurements of 25 different apples. (A) Heavily irrigated plot. (B) Lightly irrigated plot

In several preceding tables the percentage of water-core has been reported for the various sizes of apples as well as in totals for the different plots. In most cases the larger sizes had higher percentages of the disease than the smaller ones. The data of Tables IV, VII, and X, on the relation of size to water-core, are summarized in Figure 9 on the basis of the total apples of the different sizes. About 60 per cent of the 2¾ to 3 inch, the 3 to 3¼ inch, and the 3¼ to 3½ inch sizes have been affected with water-core, while only about 44 per cent of the apples that were 2¾ inches or less have been similarly affected. The disease is evidently more prevalent on the larger sizes.

The fact that the larger sizes of apples are more susceptible to water-core than the smaller ones would lead one to expect that orchard treatments which tended to increase the size of the fruit would be favorable to the development of the disease, but the results of the previous experiments do not support this hypothesis. Both heavy irrigation and heavy application of nitrate have been marked by increased growth rate of the apples, and both treatments have been accompanied by decrease rather than increase in the percentage of water-core. While water-core is somewhat more common on the large apples from a particular tree than on the smaller ones, as shown in Figure 9, it apparently does not follow that forcing apples into more rapid growth by irrigation or fertilizers will result in a higher percentage of the disease. The more vigorous foliage and the somewhat heavier crops on the fertilized and heavily irrigated trees may be of significance in explaining this seeming contradiction.

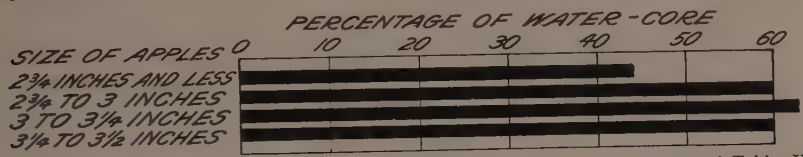

FIG. 9.—The effect of size of the apples upon the occurrence of water-core. A summary of Tables IV, VII, and X

EFFECT OF SHADE, SUNLIGHT, AND POSITION ON TREE UPON OCCURRENCE OF WATER-CORE

It was pointed out in the historical sketch at the beginning of this paper that it had been observed that water-core was not evenly distributed over the tree, but occurred most abundantly on the freely exposed fruit on the south or southwest side. In a number of the experiments of the present investigation a separate record was made for the apples from the different parts of the tree. The results are shown in Table XVI. The data are based on the total record of apples in the corresponding irrigation and fertilizer experiments previously reported. The apples described as exposed were from the more exposed limbs but were in partial shade. The apples described as shaded were from the more protected limbs, but received sufficient sunlight to have a high percentage of well-colored fruit.

A study of Table XVI shows that water-core was far more serious on the exposed than on the more or less shaded fruit. In the Winesap experiment of 1922, and in a very late picking of Jonathan in 1920, the exposed apples had but slightly more water-core than the shaded ones; but in three other experiments there was four times as high a percentage of the disease on the exposed apples as on the more protected ones; in two other cases twice as high a percentage; and in two instances the shaded apples were entirely free from water-core, with the exposed ones carrying a considerable percentage of the disease.

In some of the studies on the relation of the location in the tree to the occurrence of water-core, a record was made of the rate of evaporation under the different degrees of exposure. The results are shown in Table XVII. The atmometers in the tops of the trees were in partial shade, but were more exposed than those among the lower limbs. The different atmometers were intended to have the same relative exposure as the apples in the respective locations.

The results would indicate a considerably higher rate of evaporation in the more exposed locations. This may be of further interest when considered in connection with the studies on sap concentration on page 247.

TABLE XVI.—*Relation of the location on the tree to the susceptibility of apples to water-core*

Variety and date of picking	Percentage of water-core on apples from—			
	Exposed north	Shaded lower southwest	Exposed lower southwest	Exposed top
Northern Spy, picked Oct. 11, 1920		3.6	0	20.1
Winesap (fertilizer experiment) picked Oct. 13, 1920			23.5	23.0
Winesap (irrigation experiment) picked Oct. 25, 1920		33.3	63.9	79.7
Jonathan, picked Sept. 22, 1921		2.3		7.4
Jonathan, picked Oct. 15, 1921		60.4		65.2
Jonathan, picked Sept. 22, 1922	16.1	15.8	52.7	69.1
Winesap, picked Oct. 24, 1922	85.9	60.6	86.3	90.9
Winesap, picked Oct. 21, 1923		49.9		88.1
Rome Beauty, picked Oct. 4, 1924	0	0	17.7	
	Shaded interior		Exposed top and lower southwest	
Jonathan, picked Sept. 6, 1924	0		5.5	
King David, picked Sept. 5, 1924	0		0.6	
Rome Beauty, picked Oct. 4, 1924	3.1		32.5	

TABLE XVII.—*Rate of evaporation at different locations in the same tree*

Variety, treatment, and period of observation	Evaporation ratio (cubic centimeters evaporated per atmometer).	
	In top partially shaded	In shade of lower limbs
Yellow Newtown, Aug. 23 to 30, 1919:		
Heavily irrigated	172.5	148.5
Lightly irrigated	188.0	157.0
Winesap, July 19 to Sept. 18, 1920:		
Heavily irrigated	184.6	174.4
Lightly irrigated	200.0	192.1
Jonathan, July 1 to Sept. 22, 1922	1,860.3	1,341.0

In the 1923 Jonathan experiments on fertilizers, the apples were sorted at picking time into different lots on the basis of color and sunburn, and separate records were made as to the percentage of water-core. In a picking made September 14, the bright-red apples with a touch of sunburn had 31 per cent of water-core, and the bright-red apples with no sunburn 3 per cent. In a picking made October 5, the apples showing more or less sunburn had 57 per cent of water-core, and the bright-red apples without sunburn had 46 per cent.

The contrasts shown in Table XVI and in the Jonathan apples that were graded on the basis of color and sunburn are very significant as to the relation of sunlight to water-core, but they fall far short of the contrasts obtained from examination of individual apples

and groups of apples as picked from the tree. It was often found that water-core was confined entirely to a few scattering apples that were extremely exposed and had developed a slight sunburn. In many cases it was possible to go over the trees and pick out the water-core apples by their location on the tree and their high but bronze-tinted color. It was also observed that the apples from trees that were devitalized and carried a sparse foliage were likely to be affected with water-core.

It was quite common with sunburned apples for the more exposed half to be affected with water-core and the shaded half to be entirely free from the disease.

A number of experiments were made to determine the effect of artificial shade or inclosure upon the development of water-core. Apples or clusters of apples were selected before water-core had begun to appear, and some of these were covered with glassine bags or medium-grade muslin sheeting, and the others were left freely exposed. The glassine bags were translucent and reduced the amount of light reaching the apples. They were practically impervious to water, and were tied so as to enclose the individual apples, thus tending to restrict transpiration. The muslin was pinned over clusters of apples without actually inclosing them. It reduced the light and lowered the temperature, but without any great restriction in the air movement over the apples. The effect of these treatments upon water-core is shown in Table XVIII.

TABLE XVIII.—*Effect of artificial shade or inclosure upon the development of water-core*

Variety	Date when shaded	Date of picking	Percentage of water-core in—		
			Apples in glassine bags	Apples shaded by muslin	Apples not shaded
Yellow Transparent	July 2, 1921	July 25, 1921	28.0		20.2
Jonathan	Aug. 13, 1921	Oct. 15, 1921	78.3		66.7
Winter Banana	Aug. 6, 1923	Aug. 24, 1923	24.6		16.1
Do	do	do		5.3	32.7
Do	July 30, 1924	Aug. 22, 1924		0	69.0
Jonathan	Aug. 31, 1923	Sept. 14, 1923		0	21.7
Do	do	Oct. 5, 1923		53.5	47.6
Winesap	Sept. 4, 1923	Oct. 31, 1923		64.4	75.9
King David	July 30, 1924	Sept. 6, 1924		0	2.4
Do	do	Sept. 25, 1924		65.0	78.6

The glassine bags apparently favored the development of water-core, but the muslin shading apparently decreased the disease, and the decrease was very decided except in instances of very late picking, where even the apples in the shade developed a high percentage of water-core.

A study of the data from various experimenters shows that the degree of shade and the intensity of the sunlight had a greater bearing on the occurrence of water-core than irrigation or fertilizers. In view of this fact it seems probable that at least a part of the favorable effect of fertilizers and heavy irrigation should be attributed to a greater shading resulting from heavier foliage.

No studies have been completed as to the relative importance of the light and heat effects of sunlight in the production of water-core,

but the writers are of the opinion that temperature is more significant than light. Air temperatures of 90° to 100° F. are not uncommon in Wenatchee, and, as was pointed out in an earlier publication,[3] the exposed side of exposed apples may often have a temperature 15° to 20° F. higher than that of the air in the shade.

EFFECT OF MATURITY OF THE FRUIT UPON THE DEVELOPMENT OF WATER-CORE

In some of the experiments, several different pickings were made and the percentage of water-core was determined for each picking. The apples were taken as they came on the tree without any selection as to color or ripeness. The early pickings were made at the very beginning of the commercial harvesting period for the variety, and the late pickings after the usual harvesting period had passed. The results are shown in Table XIX.

TABLE XIX.—*The relation of the date of picking to the prevalence of water-core*

Variety and year	Picked early		Picked late	
	Date	Percentage of water-core	Date	Percentage of water-core
Jonathan, 1921	Sept. 22	4.9	Oct. 14	68.8
Jonathan, 1923	Sept. 14	13.6	Oct. 5 Nov. 4	50.0 97.9
Jonathan, 1924	Sept. 6	1.4	Sept. 27	96.5
King David, 1924	Sept. 5	0.6	Sept. 25	78.5
Winesap, 1924	Oct. 3	2.6	Oct. 27	95.6

In the early pickings there was about 14 per cent of the disease in one instance, but less than 5 per cent in all other cases, while in the late pickings 50 to 98 per cent of the apples were affected. During and immediately following the harvesting season there was an enormous increase in the disease.

In 1924 the maturity of the early and late picked Jonathan apples was determined by pressure tests. On September 6 the fruit tested 16 pounds, while on September 27 it tested 14.5 pounds. With a softening represented by 1.5 pounds difference in resistance to pressure, the water-core increased from 1.4 per cent to 96.5 per cent (Table XIX). Nearly all of this increase in the disease occurred during the latter half of the period covered, since an additional picking made on September 16 was found to be practically free from water-core.

If the results of Table XIX are compared with those reported in the previous pages, it becomes evident that the question of the maturity of the fruit completely overshadows the effects of irrigation and fertilizer and stands with exposure to sunlight as one of the prime determining factors in the occurrence of water-core. It would seem from the data collected that if rains during the harvesting season appear to result in an increase in water-core, as various writers have reported, careful consideration should be given to the possibility of the apples having become overmature as a result of the delays occasioned by the rain or because of undue waiting for color.

[3] BROOKS, C., and FISHER, D. F. SOME HIGH TEMPERATURE EFFECTS IN APPLES: CONTRASTS IN THE TWO SIDES OF AN APPLE. Jour. Agr. Research 32: 1–16, illus.

It is evident in the data reported on pages 22 and 23, and it was noted in other cases, that in the earlier pickings water-core was confined largely to the more exposed fruit, but that in the late pickings it was often found on the shaded as well as the sunburned apples. This fact should be of further interest in connection with the studies on sap concentration.

SAP CONCENTRATION AND ACIDITY IN RELATION TO WATER-CORE

The fact that water-core decreased with heavy irrigation and with application of fertilizer, and increased with intensity of sunlight and with overmaturity, made it seem probable that studies on sap concentration and acidity might throw some light on the nature of the disease. Tests along this line were started in the summer of 1923.

A study was made of both leaf and fruit tissues. The material was collected from various representative locations on the limb or tree and placed immediately in tight containers. The osmotic determinations on the leaves were made upon return to the laboratory, and those on the apples usually within a few hours after collection. Ten to twenty apples were included in each sample. Usually the whole apple was not ground, but a part of each apple included in a composite sample. The samples to be compared were taken from the same relative position on the apple with reference to the blush area and consisted of wedge-shaped longitudinal sections extending to the core.

The leaf and apple tissue was ground in a small meat chopper and the juice was extracted by means of a tincture press The osmotic determinations were made by the freezing-point method with a Beckmann thermometer. The results of the various tests are given in Tables XX, XXI, XXII, XXIII, XXIV, and XXV.

Extractions with and without freezing the tissue gave practically no contrast in sap concentration; and as a part of the juice was to be used later in sugar analyses the authors considered it advisable to make the extractions by the latter method. All of the data reported were obtained from extractions made without freezing the tissue.

The data reported on Winesap in Table XX show that the sap concentration of both the foliage and fruit was greater in the afternoon than in the morning. This fact is in agreement with the experimental results on other plants reported by various writers.

It will be seen from Tables XX and XXI that the sap concentration was greater in the leaves than in the apples, showing, as has been pointed out by Chandler *(10)* and others, that the foliage is able to draw water away from the fruit in cases where the supply is insufficient for both.

The sap concentration and acidity tests from the irrigation plots are shown in Table XX. In 5 tests on Winesap leaves, 6 on Winesap apples, and 2 on King David leaves the sap concentration was decidedly greater in the lightly irrigated plot than in the heavily irrigated one, while in 3 tests on King David apples the lightly irrigated plot showed a lower sap concentration than the heavily irrigated one. In general, the results probably can be said to indicate that an increase in irrigation tends to produce a decrease in sap concentration. It should be recalled in this connection that the

apples from the heavily irrigated plots had a slightly lower percentage of water-core than those from the lightly irrigated plots (Tables XII and XIV).

TABLE XX.—*Effect of irrigation upon sap concentration and acidity (collections at different times in the day)*

Description of samples	Osmotic pressure in atmospheres		Acidity in cubic centimeters of N/10 NaOH required to neutralize 10 cubic centimeters of extract	
	Heavy irrigation	Light irrigation	Heavy irrigation	Light irrigation
Winesap, 1923:				
Leaves collected—				
10 a. m. Aug. 15	20.63	23.94	----------	----------
5.30 a. m. Aug. 30	18.82	20.45	----------	----------
2.30 p. m. Aug. 30	22.86	23.64	----------	----------
9 a. m. Sept. 11	20.93	20.93	----------	----------
3 p. m. Sept. 11	25.86	26.47	----------	----------
Apples collected—				
10 a. m. Aug. 15	12.45	13.65	13.8	13.5
5.30 a. m. Aug. 30	13.41	14.44	10.3	11.0
2.30 p. m. Aug. 30	14.56	15.04	10.7	10 4
9 a. m. Sept. 11	14.80	15.04	10.0	9.3
3 p. m. Sept. 11	15.76	15.70	9.3	10.7
Apples picked Oct. 22, samples taken Nov. 1	17.92	18.11	7.6	7.4
King David, 1924:				
Leaves collected 9.30 a. m. July 19, 18 hours after the completion of a 3-day irrigation on both plots	23.44	24.82	----------	----------
Leaves collected 10 a. m. July 28	27.39	27.87	----------	----------
Apples collected 9.30 a. m. July 19, 18 hours after the completion of a 3-day irrigation on both plots	15.88	15.76	9.9	10.0
Apples collected 10 a. m. July 28	16.48	16.30	10.35	10.75
Apples picked Sept. 5 and stored at 70° F. till Sept. 9	23.56	21.76	7.35	6.05

TABLE XXI.—*Effect of nitrate and potash fertilizers upon sap concentration and acidity*

Description of samples	Osmotic pressure in atmospheres			Acidity in cubic centimeters of N/10 NaOH required to neutralize 10 cubic centimeters of extract		
	Potash	Nitrate	Untreated	Potash	Nitrate	Untreated
onathan, 1923:						
Collected Sept. 14—						
Red apples, not sunburned	20.33	22.86	21.29	9.5	9.3	8.5
Red apples, slightly sunburned	23.70	26.59	24.18	8.5	7.2	7.9
Collected Sept. 22—						
Red apples, not sunburned	----------	22.44	20.57	----------	8.6	9.2
Red apples, slightly sunburned	----------	23.52	21.53	----------	8.2	7.4
Collected Oct. 6—						
Red apples, not sunburned	20.27	19.85	20.43	9.8	9.0	9.2
Red apples, slightly sunburned	22.01	23.58	23.70	8.5	9.1	7.8
Jonathan, 1924:						
Collected 10 a. m. July 21—						
Leaves, fertilizer in 1924 only	22.96	26.13	26.07	----------	----------	----------
Leaves, fertilizer for 4 years	26.01	24.40				
Apples, fertilizer in 1924 only	14.80	16.06	15.10	9.85	10.0	9.5
Apples, fertilizer for 4 years	15.40	15.46		9.8	9.2	
King David, 1924:						
Leaves collected 9.30 a. m. July 19	----------	24.16	23.44	----------	----------	----------
Leaves collected 10 a. m. July 28	----------	27.87	27.39	----------	----------	----------
Apples collected 9.30 a. m. July 19	----------	15.69	15.88	----------	----------	----------
Apples collected 10 a. m. July 28	----------	16.36	16.48	----------	11.6	10.35
Apples picked Sept. 5, determinations Sept. 9	----------	23.56	23.56	----------	7.35	7.95

The results of sap concentration and acidity tests from the fertilizer plots are given in Table XXI. The data are not always consistent, but in most cases the sap concentration of the apples from the nitrate plots was higher, and that from the potash plots somewhat lower, than that of the apples from the unfertilized plots. In Table XV it was shown that at the time of commercial picking the apples from the Jonathan nitrate and potash plots of 1923 and 1924 had slightly less water-core than the apples from the untreated plots.

TABLE XXII.—*Relation of shade and location on the tree to sap concentration and acidity*

Description of samples	Osmotic pressure in atmospheres		Acidity in cubic centimeters of N/10 NaOH required to neutralize 10 cubic centimeters of extract	
	Exposed	Shaded	Exposed	Shaded
Natural shade:				
Winter Banana, collected Aug. 23, 1923—				
Leaves from lower limbs	27.55	22.62	----------	----------
Apples from lower limbs	15.40	14.20	13.2	11.6
Apples from the top of the tree	16.36	----------	12.4	----------
Winesap apples, collected Nov. 3, 1923—				
From lightly irrigated plot [a]	17.68	16.60	8.6	7.6
From heavily irrigated plot [a]	16.90	15.76	7.6	----------
Light irrigation followed by heavy [a]	19.25	16.96	7.6	8.3
As above, but apples with poor color	----------	16.54	----------	7.8
Winter Banana apples, collected Aug. 5, 1924—				
Good color	16.30	15.64	6.7	6.8
Poor color	16.00	15.16	7.0	6.9
Artificial shade with muslin:				
Winter Banana, shade applied Aug. 6, collected Aug. 24, 1923—				
Apples slightly sunburned	17.08	16.60	8.4	7.6
Apples not sunburned	16.12	14.98	9.7	8.3
Jonathan, shade applied Aug. 3—				
Collected Oct. 5, 1923—				
Apples with high color	23.70	19.91	7.8	8.3
Apples with poor to medium color	20.43	19.25	9.2	8.8
Collected Nov. 5, overripe	20.21	20.45	8.9	7.9
Winesap, shade applied Sept. 4, 1923, collected Oct. 31—				
Light irrigation, apples with good color	18.11	17.44	7.4	7.3
Light irrigation, apples with poor color	----------	17.38	----------	6.5
Heavy irrigation, apples with good color	17.92	17.14	7.6	7.6
Heavy irrigation, apples with poor color	----------	17.41	----------	7.6
Winter Banana, shade applied July 25, 1924, apples collected Sept. 11	16.24	14.44	3.6	3.9

[a] Shaded fruit well colored; exposed fruit deep red color.

The effects of exposure and of natural and artificial shade are shown in Table XXII. The apples which were well exposed to sunlight had a decidedly higher sap concentration than those which received various degrees of shading. This was true with both the highly colored and the poorly colored fruit. In Table XVII it was pointed out that the rate of evaporation was greater in the exposed locations in the tree than in the more shaded ones, and in Tables XVI and XVIII it was shown that the apples from the more exposed locations were much more susceptible to water-core than those that received a considerable degree of natural or artificial shade.

TABLE XXIII.—*Relation of sunburn to sap concentration and acidity; contrasts between the opposite sides of the same apples*

Description of material	Osmotic pressure in atmospheres		Acidity in cubic centimeters of N/10 NaOH required to neutralize 10 cubic centimeters of extract	
	Sunburned	Not sunburned	Sunburned	Not sunburned
Comparing sunburned apples with highly colored ones that were not sunburned:				
Winter banana—				
Collected Aug. 23, 1923	17.50	16.36	11.6	12.4
Collected Aug. 24, 1923	17.08	16.12	8.4	9.7
Collected July 22, 1924	19.18	16.87	7.4	7.6
Collected Aug. 8, 1924	19.12	17.32	4.2	5.5
Jonathan, 1923:				
From nitrate plots, Sept. 14	26.59	22.86	7.2	9.3
From potash plots, Sept. 14	23.70	20.33	8.5	9.5
From unfertilized plots, Sept. 14	24.18	21.29	7.9	8.5
From nitrate plots Sept. 22	23.52	22.44	8.2	8.6
From unfertilized plots, Sept. 22	21.53	20.57	7.4	9.2
From nitrate plots, Oct. 6	23.58	19.85	9.1	9.0
From potash plots, Oct. 6	22.01	20.27	8.5	9.8
From unfertilized plots, Oct. 6	23.70	20.43	7.8	9.2
Rome Beauty—				
Collected Oct. 2, 1923	18.17	16.84	3.5	5.2
Comparing the sunburned quarters of apples with the opposite quarters:				
Winter Banana, July 22, 1924	19.60	18.76	7.1	7.8
Do	15.88	13.96	5.9	6.3
Winter Banana, Aug. 5, 1924	19.12	17.08	5.7	----------

TABLE XXIV.—*Relation of sap concentration and acidity to water-core*

Description of material	Osmotic pressure in atmospheres		Acidity in cubic centimeters of N/10 NaOH required to neutralize 10 centimeters of extract	
	Water-core	No water-core	Water-core	No water-core
Water-core apples and similar apples free from water-core:				
Winter Banana—				
Aug. 5, 1924	19.12	16.30	5.7	6.7
Aug. 14, 1924	18.70	16.24	5.3	6.0
Aug. 16, 1924	18.46	15.47	4.9	5.3
Aug. 19, 1924	19.00	14.56	3.3	5.2
Aug. 21, 1924	19.24	17.08	4.8	5.2
Do	18.28	15.58	5.6	5.7
Sept. 11, 1924	17.68	15.04	3.1	4.0
Sept. 23, 1924	16.84	15.64	3.1	3.1
Winesap, Sept. 23, 1924	18.58	17.20	3.8	5.1
Water-core tissue and normal or only slightly water-cored tissue from the same apples:				
Winter Banana, Aug. 25, 1923	19.85	15.64	6.0	10.4
Rome Beauty, Oct. 2, 1923	18.65	17.68	3.7	3.2
Winter Banana, Aug. 21, 1924	19.24	19.00	4.8	4.8
Winesap, Sept. 23, 1924	19.72	17.44	3.4	4.3
Opposite quarters of the same apples (cut longitudinally to the core):				
Winter Banana—				
Aug. 5, 1924	19.84	17.08	4.9	5.7
Aug. 8, 1924	19.12	17.32	4.2	5.6
Aug. 14, 1924[a]	19.36	18.04	4.8	5.8
Aug. 16, 1924[b]	19.84	17.08	3.6	5.2
Aug. 19, 1924[a]	19.00	15.64	3.3	4.6
Aug. 21, 1924[a]	18.88	17.68	5.3	5.8
Sept. 11, 1924[a]	19.12	16.24	2.7	3.6

[a] Bad water-core

[b] Flecked with water-core.

The contrasts between sunburned fruit and well-colored fruit that was not sunburned are shown in Table XXIII. The sunburned fruit had a much higher sap concentration in all of the tests, and it usually had a lower acidity, than the fruit that was free from sunburn. The sunburned quarters of exposed apples also had a higher sap concentration and lower acidity than the opposite quarters. It was pointed out on page 245 that sunburned apples were particularly susceptible to water-core.

The sap concentration and acidity of water-core apples is shown in Table XXIV. It will be seen that the water-core tissue had a higher sap concentration and lower acidity than the normal tissue. This was true whether the water-core apples were compared with normal apples, the water-core tissue with sound tissues of the same apples, or the quarters of the apples affected with water-core with the opposite quarters that were free from the disease. The contrasts were striking in practically all cases, the sap concentration of the water-core tissue running two to four atmospheres higher than that of the normal tissue and the average acidity of the normal tissue some 14 per cent higher than that of the water-core tissue. It was pointed out in an earlier publication[4] that the sap concentration on the blush side of an apple is often three-fourths of an atmosphere higher than that on the opposite side of the same apple. In a number of the instances reported in Table XXIV, where the quarters of apples affected with water-core were compared with the opposite quarters, a similar comparison was made at the same time with the blushed and shaded quarters of normal apples. The sap concentration of the normal tissue of the water-cored apples ran a half to one and a half atmospheres higher than the sap concentration of the blush side of normal apples, and one to three atmospheres higher than the sap concentration of the greener or shaded side of the normal apples. Evidently high sap concentration is characteristic not only of water-core tissue but also, in lesser degree, of the sound tissue of water-core apples.

The collections of Tables XX to XXIV, inclusive, were made at different times and from various orchards, and most of them do not, therefore, give an opportunity for a study of the seasonal trend of sap concentration. Repeated collections, however, were made from some of the orchards and under conditions that would allow a seasonal comparison. The results are shown in Table XXV. There was usually a gradual increase in sap concentration, and a decrease in acidity, during and preceding the normal picking season. The Jonathan data seem to be an exception to this rule, but in this case the collections were all made after the normal picking season.

A comparison of the results on sap concentration with those on water-core shows a close agreement throughout, unless an exception be made in regard to the nitrate fertilizers. Neither sap concentration nor water-core was greatly affected by fertilizers or irrigation, but in the potash and irrigation experiments the conditions which resulted in a lower sap concentration also resulted in a decrease in water-core, while in the nitrate experiments this was apparently not true. It is possible that the better foliage, the increased shade, and

[4] Brooks, C., and Fisher, D. F. SOME HIGH TEMPERATURE EFFECTS IN APPLES: CONTRASTS IN THE TWO SIDES OF AN APPLE. Jour. Agr. Research 32: 1–16 illus. 1926.

the later maturing of the apples in the nitrate plot more than offset the effect of the higher sap concentration as far as water-core was concerned.

TABLE XXV.—*Relation of time of picking to sap concentration and acidity*

	Osmotic pressure in atmospheres		Acidity in cubic centimeters of N/10 NaOH required to neutralize 10 cubic centimeters of extract	
	Normal apples	Sound tissue from sunburned or water-core apples	Normal apples	Normal tissue from sunburned or water-core apples
Jonathan, 1923:				
Collected Sept. 14	21.29	24.18	8.5	7.9
Collected Sept. 22	20.57	21.53	9.2	7.4
Collected Oct. 6	20.43	23.70	9.2	7.8
King David, 1924:				
Collected July 19	15.77	----------	9.9	----------
Collected July 28	16.39	----------	10.45	----------
Collected Sept. 5	22.96	----------	7.1	----------
Winter Banana, 1924:				
First orchard—				
Collected July 22, 1924	14.50	13.96	6.3	6.3
Collected Aug. 19	14.32	15.64	5.1	4.6
Collected Sept. 23	17.20	17.44	5.1	4.3
Second orchard—				
Collected Aug. 5, 1924	15.40	17.08	6.9	5.7
Collected Aug. 21	16.60	19.01	5.4	4.8
Winesap, 1923:				
Heavy irrigation—				
Collected Aug. 15	12.45	----------	13.8	----------
Collected Aug. 30	14.56	----------	10.7	----------
Collected Sept. 11	15.76	----------	9.3	----------
Collected Oct. 22	17.92	----------	7.6	----------
Light irrigation:				
Collected Aug. 15	13.65	----------	13.5	----------
Collected Aug. 30	15.04	----------	10.4	----------
Collected Sept. 11	15.70	----------	10.7	----------
Collected Oct. 22	18.11	----------	7.4	----------

In all of the other experiments the correlation was very striking. Exposed apples and sunburned apples had a much higher sap concentration than the more protected ones, and were far more susceptible to water-core; and the exposed and sunburned sides or quarters of apples had a much higher sap concentration and a far greater susceptibility to water-core than the opposite sides or quarters. Apples increased in sap concentration with maturity with a parallel increase in susceptibility to water-core. The results show that a high-sap concentration is an accompaniment of water-core, and they suggest that it has a close connection with the cause of the disease.

The fact that sap concentration and susceptibility to water-core both increase with maturity would give further emphasis to the importance of picking the apples at the proper time. It should be noted, however, that water-core apples collected early in the season had a higher sap concentration than normal apples collected late in the season and it should be kept in mind that the sap concentrations that accompany water-core represent a diseased condition and one not to be found in normal apples.

PARTIAL RECOVERY IN STORAGE

The grower who finds his harvested fruit affected with water-core still has hopes of recovery in storage. To just what extent water-core apples can be expected to recover in storage is an important question in determining the disposition of the fruit. In a number of the experiments previously reported some of the affected apples were followed through storage to obtain evidence on this point. In most cases water-core was not evident in surface view so it was necessary to cut open some of the apples at each inspection. Water-core apples have a higher specific gravity than those which are not water-cored, but it was not found possible to use this characteristic as a means of detecting mild cases of the disease. It was found, however, that the water-core tissue gave a better transmission of light than the normal tissue, and could be fairly well located by a candling process similar to that used on eggs. A 100-watt electric lamp was used as the source of light. The "candling" method was of considerable value in determining the nature and extent of the disease, but it was always checked by data obtained by the actual cutting of the apples.

In the 1919 experiments, notes were taken on part of the Winesap and Yellow Newtown apples on November 12, and similar lots were held in cellar storage till March 9 and 10 for later notes. The cellar temperature ranged from 0 to 8° C. (32° to 46.4° F.) and averaged about 4° C. (39.2° F.). In the November notes 15 bushels of Winesap and 25 bushels of Yellow Newtown were included in the record, and in the March notes 5 bushels of Winesap and 12 bushels of Yellow Newtown. The results are shown in Table XXVI.

TABLE XXVI.—*Behavior of water-core apples in cellar storage, 1919 experiments*

Size of apples	Percentage of apples affected				
	Winesap		Yellow Newtown		
	Water-core Nov. 12, 1919	Water-core Mar. 10, 1920	Water-core Nov. 12, 1919	Water-core Mar. 10, 1920	Internal browning Mar. 10, 1920
2¾ inches and less	45.5	1.6	8.2	0.5	27.4
2¾ to 3 inches	69.2	3.0	21.5	0.0	46.8
3 to 3¼ inches	72.3	13.9	33.3	2.4	62.4
3¼ to 3½ inches	69.0	44.4	49.8	1.7	79.7

During the four months of storage, water-core disappeared almost entirely from the Yellow Newtown and from the two smaller sizes of Winesap. With the 3 to 3¼ inch Winesap it was reduced to about one-fifth the former amount, and with the 3¼ to 3½ inch size to about two-thirds the percentage found on the earlier date.

At the time of the March record a few of the Winesap had a brownish tint in the region of the large vasculars that was apparently an after effect of water-core, but in most cases the apples that were free from water-core appeared entirely normal. With the Yellow Newtown a very different condition prevailed; water-core had disappeared but internal browning [5] had developed. In the examination of

[5] The typical internal browning of Yellow Newtown, characterized by a browning of the flesh without distinct softening.

November 12 only 0.4 per cent of the apples showed internal browning, while it will be seen from Table XXVI that in the examination of March 10, 27 to 80 per cent of the apples were affected. There was a much higher percentage of this trouble in March than there was of water-core in November, indicating that much of the browning did not actually follow water-core, but there was a close correlation between the two diseases in the susceptibility of the different sizes of apples and in the location and pattern of the affected tissues, and the water-core tissue that remained frequently had a margin of typical browning (pl. 1, D). These facts, together with the almost complete disappearance of the watery tissue during storage, would indicate that a considerable part of the internal browning was an after-effect of water-core.

In the November examination of Yellow Newtown, 15 apples were found with water-core that was visible on the surface, and these were held in storage as a separate lot. In the March examination 1 apple had entirely recovered, 3 had internal browning and no water-core, 6 had internal browning with some water-core, and 5 remained apparently unchanged. From the commercial standpoint, it might be said that there was practically no recovery in storage with this lot.

In 1920 storage tests were made on Winesap and Stayman Winesap that were affected with water-core. The apples were mostly of the smaller sizes. There was 1 box of Stayman Winesap and 2 to 4 boxes of Winesap under each storage condition. The Stayman Winesaps were in storage from November 5 till March 20, and the Winesaps from November 6 till June 18. The results are shown in Table XXVII.

TABLE XXVII.—*Behavior of water-core apples in storage, 1920 experiments*

	Percentage of apples affected					
	Before storage			After storage		
	With water-core	With browned vasculars	With internal breakdown	With water-core	With browned vasculars	With internal breakdown
Stayman Winesap:						
In cellar storage	Very high.	----------	----------	42	----------	45
In cold storage	Very high.	----------	----------	41	----------	47
Winesap, first orchard:						
In cellar storage	73.1	0	0	0	0	63.2
Winesap, second orchard:						
In cellar storage	93.0	2	0	0	28.2	0
In cold storage	93.0	2	0	0	36.7	2.7

The Stayman Winesap made little recovery, either in cellar or commercial cold storage, such disappearance of water-core as occurred being offset by the development of internal breakdown.[6] The Winesap made a complete recovery in both cellar and cold storage so far as water-core itself was concerned, but a very high percentage of the apples developed either internal breakdown or browned vascular tissue. The final notes were taken June 18, which is late in the season but no later than Winesap are often held.

[6] A browning and softening of the flesh, particularly common in overmature fruit.

In 1921, four boxes of badly water-cored Winter Banana apples were held in storage. Nearly all of the apples had visible water-core when they went into storage, and the weight and appearance of the others indicated that they were also affected with the disease. Two boxes of the apples were held in an air-cooled basement storage and the other two in commercial cold storage; the apples in the cellar storage were of the 72 and 80 sizes (number of apples to the box), while those in cold storage were of the 100 and 113 sizes. It was found on January 25 that none of the apples from cellar storage had water-core, and only 1.9 per cent of those from cold storage were affected, but 88 per cent of the cellar-storage apples and 85 per cent of the cold-storage ones had developed internal breakdown, a large part of which appeared to be centered in the tissue that had originally been affected with water-core.

In 1922, water-core notes were taken on November 4 on some of the apples from the Winesap irrigation and fertilizer plots (see p. 235), and the rest of the crop (approximately three boxes from each orchard condition) was held in cellar storage till January 18, when notes were taken again. The results are shown in Table XXVIII. There was practically no visible water-core at the time of the first note-taking, and in most cases the affected tissue was confined to small areas between the carpel walls or around the main vasculars.

TABLE XXVIII.—*Behavior of water-core on Winesap apples in storage, 1922 experiments*

Plot and orchard treatment	Percentage of water-core on apples of the following sizes							
	2¾ inches or less		2¾ to 3 inches		3 to 3¾ inches		3¼ to 3½ inches	
	Nov. 4	Jan. 18	Nov. 4	Jan. 18	Nov. 4	Jan. 18	Nov. 4	Jan. 18
1. Heavy irrigation (records of Nov. 4 and Nov. 23 combined)	54.9	5.1	70.0	1.7	88.7	0	88.9	0
2. Light irrigation (records of Nov. 4 and Nov. 23 combined)	77.4	13.4	82.1	16.5	89.4	26.3	80.0	0
3. Light irrigation followed by heavy	38.3	24.1	57.1	41.0	86.7	56.4	100.0	66.7
4. Heavy irrigation followed by light	67.2	4.9	82.4	23.1	84.6	40.0	-------	-------
5. Nitrate of soda	87.5	40.9	94.8	32.4	98.4	38.3	100.0	40.0
6. Muriate of potash	86.2	4.1	92.7	5.8	98.2	6.5	100.0	0
Total for all plots	63.0	8.8	77.8	19.4	92.7	32.0	94.6	24.0

The recovery from water-core in storage was not so complete as in the 1919 and 1920 experiments, but the notes were taken much earlier. The apples from the heavy irrigation and potash plots made the most complete recovery. It will be seen from the totals for all the plots that the smaller-sized apples made a much more complete recovery than the larger-sized ones. With the apples that were 2¾ inches or less water-core was reduced in storage to about one-seventh the original amount; with the 2¾ to 3 inch apples to about one-fourth the original amount; and with the 3 to 3¼ inch apples to about one-third the original amount. In a few instances water-core was followed by internal breakdown, but in most cases the previously water-cored apples had no evident after effects of the disease.

TABLE XXIX.—*Behavior of water-core apples in storage, 1923 experiment*

Variety and orchard treatment	Percentage of apples affected			
	Before storage		After storage	
	Water-core	Internal break-down	Water-core	Internal break-down
Jonathan; in cellar storage Oct. 5 to Feb. 2:				
From nitrate plot	34.6	0	0	0
From potash plot	71.8	0	0	6
From unfertilized plots	47.2	0	0	29.2
Mixed lot from all the plots:				
In oiled wraps	50.2	0	0	7.6
In common wraps			0	0
Winesap; in cellar storage Oct. 3 to Apr. 10:				
Heavy irrigation	57.5	0	0	0
Light irrigation	67.1	0	0	0
Heavy irrigation followed by light	82.5	0	1.2	0
Light irrigation followed by heavy	88.2	0	0	0
Rome Beauty, in cellar storage Oct. 10 to Apr. 10	100	0	7.3	89.1

Some of the apples from the 1923 orchard experiments were also held in storage for further notes on water-core. The results are shown in Table XXIX. While water-core was bad at picking time, the recovery in storage was practically complete on both Jonathan and Winesap. Some internal breakdown developed on Jonathan, apparently as an aftereffect of water-core, but the Winesap apples from the lots that had previously shown 57 to 88 per cent of water-core came out of storage practically free from the disease and apparently entirely normal. The water-core on both these varieties was invisible (not evident in surface view). The Rome Beauty apples, on the other hand, had a high percentage of visible water-core when they went into storage, and while it will be seen that most of the disease disappeared as such, a high percentage of internal breakdown developed apparently as an aftereffect of the water-core.

TABLE XXX.—*Water-core apples in cold storage and cellar storage (Winesap, 125 size, 1923)*

Condition of storage and date of note taking	Percentage of apples			
	Sound	With water-core		With internal break-down
		Slight	Bad	
Before storage, Nov. 16	1.6	63.7	34.7	0
After cellar storage, Apr. 12:				
In oiled wrappers	48.5	33.6	10.0	7.9
In common wrappers	52.2	32.1	12.6	3.1
After cold storage, Apr. 16:				
In oiled wrappers	53.3	41.6	3.2	1.9
In common wrappers	34.8	32.6	23.9	8.7
After cellar storage, May 15:				
In oiled wrappers	54.6	41.9	1.2	2.3
In common wrappers	60.5	34.4	1.7	3.4
After cold storage, May 15:				
In oiled wrappers	40.0	54.1	1.2	4.7
In common wrapper	39.8	48.3	3.5	8.4

Badly water-cored Winesap apples from another orchard were used in a comparison of cellar storage and cold storage, and in tests on different kinds of wrappers. The results are shown in Table XXX. Practically all of the apples had water-core when they went into storage, and about half of them recovered from the disease. The recovery was slightly better in cellar storage than in cold storage, and practically the same in the oiled wrappers as in the common wrappers.

In 1924, storage experiments were carried out on badly water-cored Jonathan, Delicious, and Arkansas (Mammoth Black Twig). The results are shown in Table XXXI.

TABLE XXXI.—*Behavior of water-core apples in storage, 1924 experiments*

Variety and size of apples, and the conditions of storage	Percentage of apples affected			
	Before storage		After storage	
	Water-core	Internal breakdown	Water-core	Internal breakdown
Jonathan, in cellar storage about 70° F.:				
Sept. 17 to Sept. 26	8.8	----------	1.1	----------
Sept. 29 to Oct. 18—				
2¾ inches or less	93.4	0	31.6	27.4
2¾ to 3-inch size	97.3	0	42.3	44.4
3 to 3¼-inch size	100	0	36.1	42.6
3¼ to 3½-inch size	100	0	75	100
Delicious:				
In air-cooled storage—				
Oct. 3 to Dec. 17	100	0	75	0
Oct. 3 to Mar. 30	100	0	0	43.5
In cold storage—				
Oct. 3 to Feb. 10	100	0	29.8	0
Oct. 3 to Apr. 25	100	0	35.8	26.9
Arkansas (Mammoth Black Twig), in cold storage, Oct. 14 to Mar. 30	100	0	0	0

The Jonathan were held in cellar storage, and while one-half to two-thirds of the water-core disappeared within 3 weeks, a considerable amount of internal breakdown developed in its place. The recovery was better on the apples 2¾ inches or less in size than it was on the larger sizes.

In air-cooled storage, 25 per cent of the Delicious recovered by December 17 and water-core had disappeared from all of them by March 30 but on the latter date 43.5 per cent of the formerly water-cored apples had developed internal breakdown. In cold storage, about two-thirds of the Delicious had recovered by February 10. No further recovery was evident by April 25, and about one-fourth of the apples had developed internal breakdown.

All of the Arkansas apples were affected with water-core on October 14, and all of them had completely recovered by March 30.

It will be seen from the various experiments that considerable recovery from water-core can be expected during storage. With firm long-keeping varieties such as the Winesap and Arkansas the recovery has usually been fairly complete, with little complication with other troubles; but with Jonathan, Delicious, Stayman Winesap, and Rome Beauty, water-core has been somewhat more persistent, and recovery has often been accompanied or followed by internal

breakdown. Small-sized apples made a better recovery than the larger ones. The recovery from water-core was almost as complete in commercial cold storage as in air-cooled storage.

SUMMARY

Irrigation experiments have been conducted for a period of six years. Apples from lightly irrigated trees developed more water-core than those from heavily irrigated trees, and apples from trees receiving heavy irrigation followed by light usually had more water-core than those from trees receiving light irrigation followed by heavy. An excess of soil moisture late in the season showed no tendency to increase the amount of water-core.

Apples from trees receiving nitrate or potash fertilizers usually had less water-core than those from untreated trees.

Large apples showed a greater susceptibility to water-core than smaller ones, but increasing the size of the apples by irrigating or fertilizing did not increase the percentage of apples affected by water-core.

Apples that were freely exposed to sunlight showed a strong tendency to water-core, while those that were somewhat shaded were usually entirely free from the disease, except in very late pickings. Sunburned apples were extremely susceptible to water-core.

Water-core increased rapidly as the apples became over-mature.

Picking at the proper stage of maturity is the most practicable preventive now known for the disease.

There was a close correlation between sap concentration and water-core. Heavy irrigation tended to decrease both sap concentration and water-core. Exposed and sunburned apples had a very high sap concentration and were very susceptible to water-core. The exposed sides of apples had a higher sap concentration than the shaded sides, and were more susceptible to water-core. Water-core apples had a higher sap concentration than normal apples, and the water-core tissue of an apple had a higher sap concentration than the sound tissue of the same apple. Sap concentration increased with the maturity of the apples, but apples that were sunburned or water-cored early in the season had a higher sap concentration at that time than normal apples ever attained even if left on the tree several weeks after the usual picking season.

Water-cored and sunburned apples had a lower acidity than normal apples.

Water-core is apparently the result of sap exudation under pressure. The present evidence seems to point to high sap concentration as a precursor of the disease, and the writers are of the opinion that it is much more responsible for the occurrence of water-core than variations in rainfall or soil moisture.

The small-sized apples made better recovery in storage than the larger ones. The kind of wrapper had little or no effect upon the extent of recovery. In most cases the recovery was practically as complete in cold storage as in air-cooled storage. Arkansas and Winesap apples made a better recovery than Stayman Winesap, Rome Beauty, Delicious, or Jonathan. Water-core apples had a high degree of susceptibility to internal breakdown.

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